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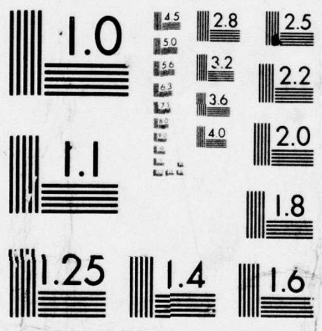

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TEMPERATURE CONDITIONS OF CONCRETE IN THE CONSTRUCTION OF THE KRASNOYARSKAYA GES UNDER WINTER CONDITIONS

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This paper reports on the temperature conditions during the construction of the Krasnoyarskaya GES under winter conditions. A series of conclusions are presented at the end of the report.

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TEMPERATURE CONDITIONS OF CONCRETE IN THE CONSTRUCTION OF THE KRASNOYARSKAYA GES UNDER WINTER CONDITIONS

ENERGETICHESKOYE STROITEL'STVO in Russian No 5, pp 31-35

[Article by N.G. Samsonov, candidate of technical sciences, and V.P. Shkarin, engineer]

[Text] A large amount of concrete work is done in winter in power engineering construction. Although the rate of placing the concrete in block structures is somewhat slower in winter, the volume of concrete placed in the winter months is still quite high. For example, the amount of concrete placed in the dam of the Bratskaya GES in winter at a temperature below 0°C was 52 percent. Some 25 percent of the total volume was placed under the protection of a winter shelter. The reduction in the intensity of placement under the winter shelter, as compared with the summer period, was about 30 percent. A similar approximate ratio was observed in the construction of the Krasnoyarskaya GES. In 1964-1967, 2, 238,000 m^3 of concrete were placed in this dam, and of them, 604,000 m^3 were placed during the winter months.

In winter concreting the cost of 1 m^3 of concrete placed increases considerably, which is because of the increase in the volume and labor-intensiveness of the work, as well as the cessation of concreting when the temperature of the outside air is below -40°C. For example, in the construction of the Bratskaya GES, the increase in cost of 1 m^3 of concrete was about 27 percent.

In spite of the widescale experimental work carried out in many countries [Bib. 1], so far there has been insufficient study of the curing of winter concrete, the periods for removing the forms, the time for cessation of the heating, etc. A study of the physical factors determining the resistance of the concrete to early freezing is very important.

According to the most recent data [Bib. 2], the increase in the strength of the concrete which is frozen after placement also takes place with prolonged curing of it at a temperature of 0 to -5°C. The increase in strength of the frozen concrete mainly takes place after thawing. In view of the structural

disarrangements with the freezing of thawed concrete which has not gathered its critical strength in time,* however, it does not completely gain it.

The results of observing the temperature conditions of concrete placed in the winter of 1967 during the construction of the Krasnoyarskaya GES are given below.

Protecting the concrete with formwork. On the specification of ensuring the necessary strength characteristics, for thermal protection of the fresh concrete, a heated form is used, with a heat transfer coefficient of K=0.6+ +0.7 kcal/m^2·hr·degree. This relatively low heat transfer coefficient for the form is obtained by protecting it with a layer of mineral wool 7-8 cm thick. The form is also warmed to reduce the temperature gradient between the center and the surface of the block, the magnitude of which from the specifications for crack resistance, should not exceed 20-25°C.

To substantiate the optimal heat transfer coefficient for the form, the authors made preliminary calculations of the one-dimensional problem of the cooling of a semi-infinite block of concrete on an all-purpose USM-1 grid model. The calculations were made for a temperature of the poured concrete of plus 5°C and of the outside air, minus 30 and minus 40°C, for different heat transfer coefficients and grades of concrete M150, V2 and M200, V8, with a content of ShPTs-400 in the amount of 180 kg/m^3 and PTs-400 in the amount of 245 kg/m^3. Used in the calculations were the values of the heat release of the cement (portland cement and portland blast furnace cement from the Krasnoyarsk Plant) and the thermophysical characteristics of various concrete, which were obtained as the result of observations made at the site in blocks of concreting of the Bratskaya and Krasnoyarskaya GES. The results of the calculations are given in Figure 1.

On the basis of the calculations it was found that for concrete of grades M150 and V2 (ordinarily used in the inner zones of concrete dams), the minimal permissible heat transfer coefficient at a temperature of the outside air ($T_{н.в}$), equal to minus 40°C, may be taken as K=1 kcal/m^2·hr·degree, at which a set of 50 percent R_{28} is ensured on the 21st day at above-zero setting temperatures. For concrete of grades M200 and V8, when $T_{н.в} = -40$°C, the set of 50 percent R_{28} is guaranteed by a form with a heat transfer coefficient of K=1.5 kcal/m^2·hr·degrees in 14 days with the average setting temperature about 2.5°C, 10 cm from the form.

Another important criterion for correct curing of the concrete is the temperature gradient, core-face** (Fig. 2). The data of the graphs were obtained under the same conditions as the data from the graphs of the temperatures

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* For norms 50% R_{28}, but not less than 50 kg/cm^2.

** The gradient core-face is defined as the difference in the temperatures at a distance of 0.1 and 3.1 m from the form. This corresponds in practice to a block 6 m high with plan dimensions of 11 X 12 m.

of the concrete depending on the heat-protective properties of the form. It can be seen from Figure 2 that gradients not higher than 25°C are ensured at $T_{н.в.}$ = -40°C with the curing time in the form not over 30 days and the following maximal values for the heat transfer coefficients of the form:

	kcal/m^2·hr·degree
For concrete grades M150, V2	1
For concrete grades M200, V8	0.75

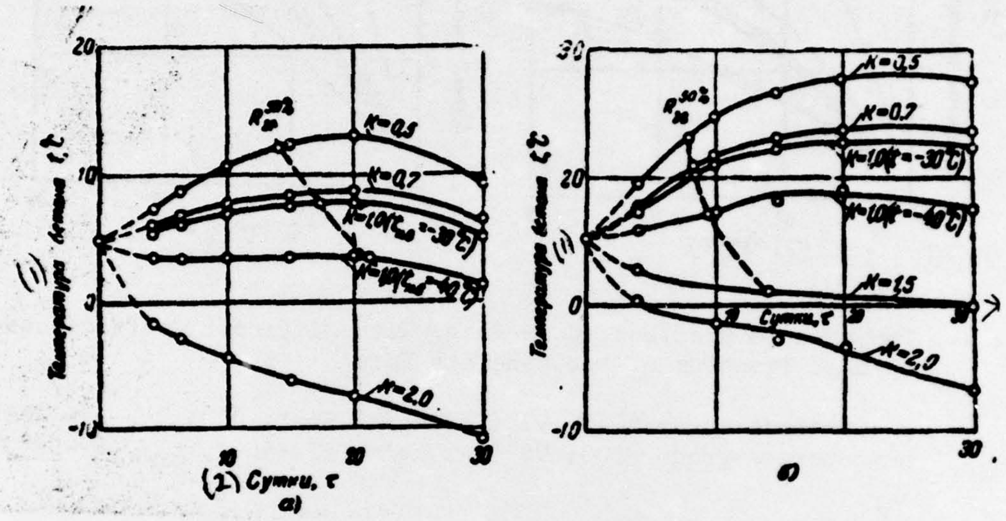

Figure 1. Relation of Temperature of Concrete to Heat-Protective Properties of the Form

a--concrete grades M150, V2 (180 kg/m^3 ShPTs-400), $F_{н.в}$ = -40°C;
b--concrete grades M200, V8 (245 kg/m^3 PTs-400), $T_{н.в.}$ = -30°C.

Key:

1. Temperature of concrete t, in °C
2. Days, t

When the temperature of the outside air is minus 30°C, these coefficients respectively increase to 1.3 and 0.95 kcal/m^2.hr.degree.

The above values of the heat transfer coefficients of the form, calculated on the basis of the specifications for crack-resistance, are valid for blocks over 6 m high, but for blocks with less height, as the result of their considerable natural cooling, higher values are permissible for the coefficients. For blocks 3 m high, with concrete grades M150 and M200, it is expedient to take K=1.10 kcal/m^2.hr.degree.

The most difficult to regulate is the thermal regime in the corners of the block. A calculation on USM-1 showed that with a heat transfer coefficient equal to 1.0 kcal/m^2·hr·degree, the corner of the block freezes to a depth of

30-40 cm. Because of this, in construction the corners of the block are heated, by lining them with roofing felt, wood-fiber panel, boards, etc.

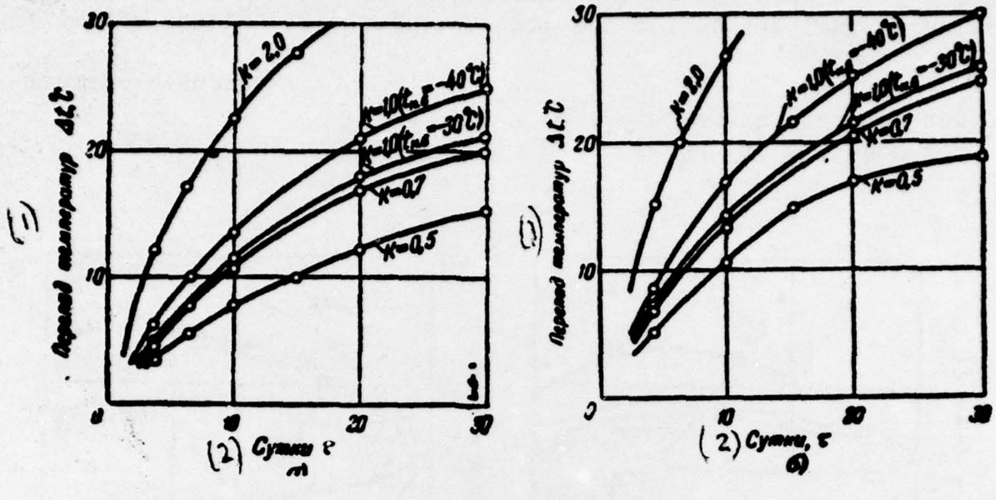

Figure 2. Temperature Gradient, Core-Face, With Different Coefficients of Heat Transfer of the Concrete Form

a--concrete grade M150, V2 (180 kg/m^3 ShPTs-400), $t_{н.в}$ = -40°C;
b--concrete grade M200, V8 (245 kg/m^3 PTs-400), $t_{н.в.}$ = -30°C.

Key:

1. Temperature gradient, Δt°C
2. Days, t

In order to determine the heat-protective properties of the formwork and its effect on the formation of the temperature conditions of the concrete in the area adjacent to it, in the winter of 1967, telethermometers were installed in several blocks of the station section of the Krasnoyarskaya dam. The diagram of their installation and the temperature curves obtained at the beginning of the concrete hardening are shown in Figure 3. In the first case the telethermometers (Fig. 3,a) were installed in the corner of the block where the panels of the formwork join. The chinks were filled in with slag wool and the connection spots were lined with a wood-fiber panel 12.5 mm thick and covered with roofing felt. In the second case (Fig. 3,b), the telethermometers were installed in the center of the face of the block, in the middle of the panel of the form. The nature of the curves of concrete heating in the initial hardening period in the corners of the blocks and in the middle of the formwork differed. Analogous curves were also obtained in other blocks. The difference in the contour of the curves of exothermic heating may result not only from the effect of the chinks between the panels of the formwork, but also from the heat release in the corners of the blocks immediately in the two planes. A comparison of the curves of exothermic heating and the curve of the temperature of the outer air (Fig. 3,c) shows that with

a sharp reduction in the temperature of the outer air in an area 0-30 cm from the corner of the block, a reduction is observed in the temperature of the hardening concrete.

In the central part of the formwork panel there are practically no fluctuations in the temperature of the surface of the concrete. The effect of the chinks in the joints of the formwork panels on the course of the exothermic heating of the concrete near the form may be shown from the example of a block 45-1-17, 18. On the ninth day after placement, in an area 2-10 cm from the form, where the panels join, the temperature was 2-3°C lower than in the central part of the panels.

The temperature gradient, core-face, on the 10th day was 9-13°C, with the temperature of the surface 10-20°C. Therefore, the natural dispersion of the exothermic heat is low, and consequently, a form used in construction with a heat transfer coefficient of 0.65 kcal/m^2.hr·degrees should be acknowledged as unnecessarily warm.

Thermal balance in the winter shelter. When concrete is placed in winter, shelters are used which are heated by electric or steam calorifiers. Work done in the winter shelters is expensive, since there is an increased input of materials for the formwork, material is needed to install the tent and there are expenditures for heat insulation and steam or electric heaters. When winter shelters are used, an attempt should be made to economize on the expenditure of material resources.

The winter shelter is a standard panel form, installed at the height of the block being concreted (3-6 m), above the edge of which (by 1.3-1.5 m) is installed a detachable cover for the tent, supported by triangular columns. The chink between the top of the tent and the edge of the form is covered with tarpaulin. The top has hatches to feed in the concrete from buckets. The cover of the tent and the tarpaulin are used many times, but a great deal of heat is lost in installing such a tent. The temperature in the shelter, because of the high blow-through tendency of the tarpaulin, which is seldom in good condition, is very uneven and depends to a great extent on the quality of the tarpaulin. Observations show that in tents supplied with good tarpaulin, the temperature of the air, given the same temperatures of the outside air, is 8-10°C higher than in tents covered with old, worn-out tarpaulin.

At present there is no precise norm set in construction for heat input to warm the concrete, since there is no actual accounting of the heat lost.

According to the existing norms, the amount of heat needed to warm the tent is determined by the formula

$$Q=\alpha_{\text{пр}}\bar{K}F\Delta t$$

where K is the coefficient of heat transfer, kcal/m^2 hr degree;
$\alpha_{\text{пр}}$ is the coefficient of degree of blow-through of the shelter;
F is the area of cooling of the surface of the heating, m^2;
Δt is the temperature gradient of the air inside and outside the tent, in degrees.

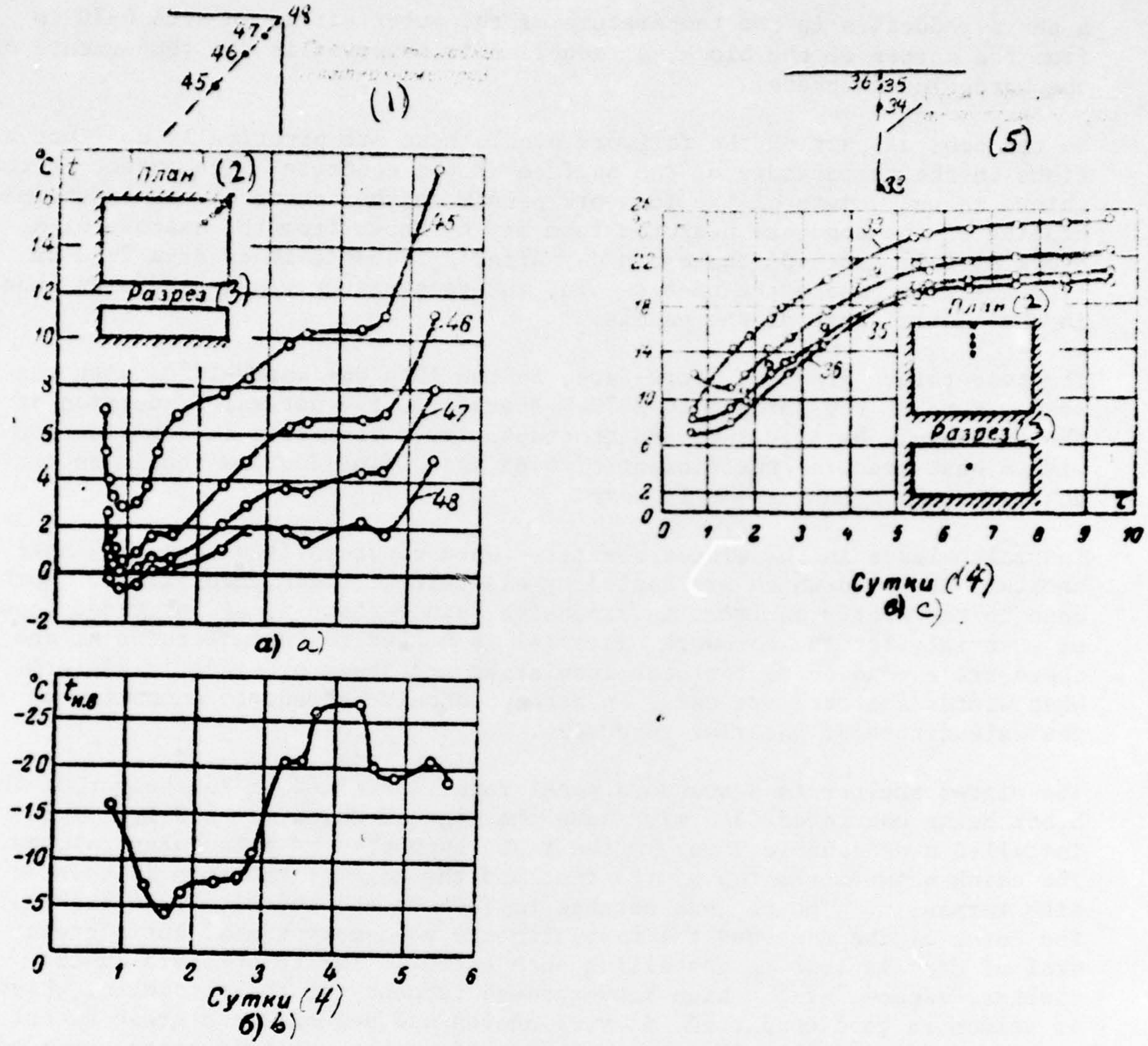

Figure 3. Graphs of the Exothermic Heating of Concrete

a--in the corner of the block (block 45-II-20, time of concreting--31 January 1967); b--temperatures of the outside air; c--in the midle of the face under pressure (block 45-1-17,18, time of concreting--31 January 1967).

Key:

1. Diagram of telethermometer installation
2. Plan
3. Section
4. Days
5. Diagram of the arrangement of the telethermometers

The least studied is the coefficient $n_{\pi p}$. The values recommended by different authors for this coefficient often vary 300-400 percent.

To determine the coefficient of the degree of blow-through of the formwork, a temperature calculation was made with respect to one of the blocks being concreted of the station section of the dam.

Block 45-1-17,18 had a shelter 7.5 m high. It was concreted in 5.5 days to a height of 6 m. The average temperature of the outside air during the observation period was -28°C, and the average wind velocity was 4-5 m/sec. The shelter was heated with two or three electric calorifiers, but the temperature of the air in the shelter on the average was -1.5°C.

The equation for the thermal balance was compiled in consideration of the average temperatures of the air in the tent and outside, and the average temperature of the concrete being placed. The heat exchange regime was practically stationary.

The heat came from two sources: from the operating electric calorifiers and the fresh concrete. Calculation of the amount of heat coming from the fresh concrete was made according to the chart for heat release of a flat panel [3].

Having assumed the coefficient of heat transfer of the concrete as K= =5 kcal/m^2 hr degree and the coefficient of heat conductivity of the concrete as λ=2.0 kcal/m·hr·degree for a layer 0.4 m thick, it was established that: with interruptions in placing the layers of 4.5-5 hours, the concrete releases to the shelter 60-65 kcal/hr with 1 m^2 of area of the block.

The heat loss through the formwork, the tarpaulin covering and the upper cover of the tent, as well as through the open hatches when the buckets are unloaded, was considered separately. The heat transfer coefficient for the tarpaulin, equal to 5 kcal/m^2·hr·degree, and the coefficient of blow-through $\alpha_{\pi p}$, equal to 3, were adopted according to [4]. The coefficients of heat transfer of the formwork, K=0.65 kcal/m^2·hr·degree and of the upper covering of the tent, K=1.5 kcal/m^2·hr·degree, were obtained by calculation for the structures of the shelter, used in the construction. The heat losses through the open hatches were determined from the formula

$$Q_1 = \Delta i G \tau$$

where Δi is the gradient of heat content of the saturated air for the temperatures outside and inside the shelter, corresponding to it, in kcal/kg;
G is the flow of air passing through the opening of the hatch, kg/sec;
τ is the time during which the hatches are open, in sec.

The calculation of the thermal balance showed almost complete equality of the entering and outgoing heat. Since the calculations used actually

observed temperatures of the air and the concrete, the thermophysical characteristics of the formwork and the tent and the heat productivity of the electric calorifiers, the coefficients of the heat transfer of the formwork, the covering of the tent and the tarpaulin, and the coefficient of blow-through of the shelter of the block should be regarded as close to the actual ones.

The greatest losses of heat take place through the tarpaulin covering of the tent. With the tarpaulin is replaced with a panel form the estimated losses of heat (expenditure of electrical power) are almost 50 percent less.

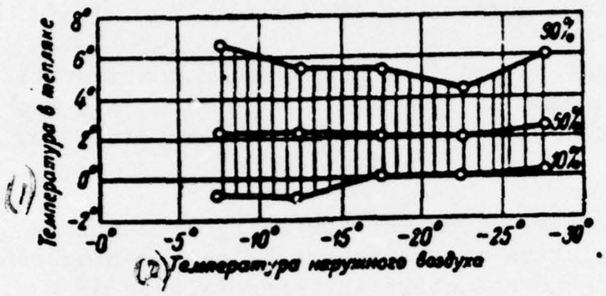

Figure 4. Relationship of the Temperature of the Air in the Shelter to the Temperature of the Outside Air

Key:
1. Temperature in the shelter 2. Temperature of the outside air

In connection with the facts presented, the values recommended in [5] for the coefficient of blow-through for approximately the same temperature gradients should be acknowledged as considerably overstated.

Temperature regime of the air in the shelter. The temperature of the air in the shelters according to the technical specifications should be above zero and should not exceed +5°C. The generalized graph of the relationship of the temperature of the air in the shelter to the temperature of the outside air, plotted from the data of mass surveys made by the concrete construction laboratory in the winter of 1964-1965 and 1965-1966, is given in Figure 4. From the graph it follows that the average temperature of the air in the shelter is in a range of 2-2.5°C and has practically no relation to the temperature of the outside air.

Observations of the temperature of the air in the shelters in the period of preparing the foundation of the block and during the concreting showed that its considerable fluctuations have almost no relationship to the height of the tent. The temperature is distributed uniformly through the area of the foundation and the height of the tent due to the low ventilating capacity of the heating units and the presence of chinks in the enclosures.

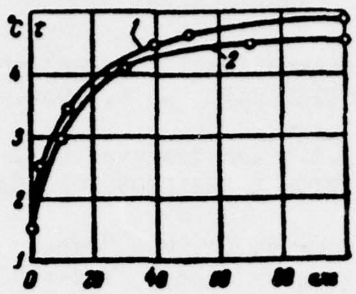

Figure 5. Relationship of Temperature of Concrete Mix (Concrete M200, V6) in the Covering Layer to the Distance to the Formwork

1--block 43-1-20, t of fresh concrete mix--7.3°C; 2--block 44-1-17,18; t of fresh concrete mix--8.5°C

Closely related to the temperature of the air in the shelter is the temperature of the concrete in the covering layer. Mass surveys in concreted blocks showed that the average temperature of the concrete in the covering layer at a depth of 4-5 cm fluctuates within a range of 6.5-7.5°C, with considerable deviations. The spread of the temperatures in the covering layer stems from the lack of uniformity in the heating of the mix at the concrete works. The lowered temperatures in the covering layer are observed in the area adjacent to the formwork. The graphs of the relationship of the temperature of the concrete to the distance to the formwork are given in Figure 5. The relationship has a clearly marked curvolinear nature at a distance up to 60 cm; at a greater distance away from the formwork, no interrelations are observed.

Conclusions

1. The coefficient of blow-through of the tent enclosure, even when it is of poor quality and with a wind velocity of 4-5 m/sec does not exceed 3.

2. In the immediate vicinity of the formwork, 5-7 hours after the placing, it is possible for the concrete to cool to a temperature close to zero and even below zero, but after 10-14 hours, the hardening takes place at temperatures above zero.

3. The coefficient of heat transfer of the formwork of 0.65 kcal/m^2 hr degree with the temperatures of the outside air minus 25-30°C, was selected with a considerable reserve; K=1.0 kcal/m$^2\cdot$hr$\cdot$degree would be more optimal.

4. The temperature of the air in the shelters should be maintained within a range of 0 to +2°C, with the concrete mix placed at a temperature of from 2 to 6°C.

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